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Thermal behavior of asphalt concrete under various microstrain levels

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ABSTRACT

Deterioration of asphalt concrete through the service life is related to the vehicular loading and environment impact. The present work assessed the influence of microstrain level and environment on the permanent microstrain and fatigue life of asphalt concrete. Beam specimens obtained from laboratory prepared slab samples of asphalt concrete were tested under dynamic flexural stresses under three microstrain levels of (750, 400 and 250). Two testing temperatures have been implemented, (5 and 30)℃. The permanent deformation in terms of microstrain was monitored. It was detected that the permanent microstrain increases by (153, 33.3 and 56.2,) % under microstrain levels of (750, 400 and 250) respectively at a testing environment of 30 °C as compared with that at testing environment of 5 °C. It was revealed that the fatigue life increases by (12.3, 2.3, 14 and 12.3) folds under microstrain levels of (750, 400 and 250) respectively when the testing environment rises from (5 to 30)℃.

Keywords: Environment, Asphalt concrete, Deformation, Microstrain level, Dynamic Flexure.

1. INTRODUCTION

An asphalt concrete mixture changes their properties under thermal conditions and loading time. Under various conditions of loading, such mixtures reveal their rheological characteristics. Fatigue of asphalt concrete depends on the durability of the mixture. Chen et al., (2021) developed a stiffness change tendency method which may be implemented to determine the critical laboratory fatigue failure points and model the stiffness in asphalt concrete. The change in the measured stiffness through fatigue life was determined by testing at various temperatures and strain levels. It was concluded that the model of stiffness development, obtained different fatigue failure criteria and characterize different fatigue damage stages, which could be useful in a simulation of pavement deterioration. Alam and Hammoum, (2015) stated that the viscoelastic behavior of asphalt concrete can characterize the mechanical properties of mixture. The relationship between individual material properties and their interaction within the microstructure was modeled. Mazurek and Iwański, (2017) compares the results from the fitting of relaxation functions in mathematical and mechanical models in conjunction with master curves constructed based on those models. It was concluded that the modelling results will provide an overarching view on the

effectiveness of use of each relaxation function. Keshavarzi et al., (2021) reported that the thermal cracking is considered as one of the most prevalent types of asphalt concrete pavement distress. Thermal damage and associated stress are significantly affected by the coefficient of thermal contraction of the mixture. A model was suggested to predict the coefficient values as the temperature drops which require the elastic modulus, mixture's volumetric properties and coefficient of thermal contraction of the aggregate.

Stefańczyk and Mieczkowski, (2008) revealed that the design of the flexible pavement structures requires the use of advanced rheological models for asphalt concrete materials. The ability to predict the variation of the stiffness modulus with temperature of asphalt concrete is critical for providing pavement structural layers with adequate durability. The most used model in the design of pavements is the elastic constitutive model. It assumes linear strain-stress relationship. Mackiewicz and Szydło, (2019) presented two methods for the identification of viscoelastic parameters of asphalt mixtures. The dynamic test and the static creep test were implemented on the bases of the four-point bending beam. The fatigue hysteresis (for dynamic test) and course of a creeping curve (for static creep) were included in the model. The analysis of test results indicated that such parameters are significantly dependent on the testing temperature, methods used, asphalt content and loading time. Ahmad et al., (2020) assessed the impact of the phase angle and temperature on dynamic complex modulus of the asphalt concrete mixtures practicing a testing temperature range of (50, 45, 40, 35 and 30) °C at various frequencies. The dynamic modulus test of the mixtures exhibit highest test results at 30°C while it gradually decrease at higher testing temperature of (35, 40, 45 and 50) °C respectively.

Liu et al., (2022) assessed the influence of annual range of temperature on annual average ground temperature and the layer thickness. The thermal parameters of the asphalt concrete layer were discussed. The test results indicated that the temperature fields of the pavement as obtained by the experimental data were verified by comparing with the numerical calculation results, it was addressed that the results are in close agreement. The aim of this investigation is to assess and model the thermal behavior of the asphalt concrete. Beam specimens will be tested for fatigue life under repeated flexural stress. The variation in the permanent deformation will be assessed and modeled under various microstrain levels.

2. MATERIAL CHARACTERISTICS AND TESTING METHODS

Materials which are implemented in this investigation are locally available and usually used for asphalt concrete paving work.

Asphalt Cement binder

Asphalt cement with a penetration grade of 40-50 was obtained from AL-Nasiriya oil refinery. The Physical properties of the asphalt cement binder are listed in Table 1.

Table 1 The Physical properties of asphalt cement

Property	Testing condition	ASTM, 2015 Designation No.	Value	SCRB, 2003 Specifications
Penetration	25˚C, 5 seconds, 100 gm	D5-06	42	40-50
Softening Point	(Ring and Ball)	D36-895	49	-
Ductility	25˚C,5cm/minutes	D113-99	100 +	>100
Specific Gravity	25˚C	D70	1.04	-
After thin film oven test properties according to ASTM D1754-97				
Penetration	25˚C, 5 seconds, 100 gm	D5-06	33	-
Ductility of Residue	25˚C,5cm/mi	D113-99	83	-

Fine and Coarse Aggregates

Crushed coarse aggregates and crushed sand have been implemented as Fine aggregate. The aggregates were obtained from AL-Ukhaider quarry. The physical properties of aggregates are listed in Table 2.

Table 2 Physical Properties of Fine and Coarse Aggregate

Property	Value	ASTM, 2015 Designation No.
Coarse Aggregate		
Bulk specific gravity	2.542	C127-01
Water absorption %	1.076%	C127-01
Wear % (lose Angeles's abrasion)	18%	C131-03

Fine Aggregate		
Bulk specific gravity	.558	C128-01
Water absorption %	.83%	C128-01

Mineral Filler

Limestone dust filer was obtained from Karbala quarry. The physical properties of the mineral filler are presented in Table 3.

Table 3 The Physical Properties of limestone dust (Mineral Filler)

Bulk specific gravity	% Passing Sieve 0.075 mm	Specific surface area (m^2/Kg)
2.617	94	312.5

Selection of Aggregate Gradation for Asphalt Concrete

The selected aggregates gradation in the present work follows SCRB, (2003) limitations for dense graded pavement layer usually implemented for wearing course. It has 12.5 mm nominal maximum size of aggregates. Table 4 shows the implemented aggregate gradation.

Table 4 The SCRB, (2003) Combined Gradation for Wearing Course

Sieve size (mm)	19	12.5	9.5	4.75	2.36	0.3	0.75
Implemented gradation	100	95	83	59	43	13	7
SCRB, (2003) limitations	100	90-100	76-90	44-74	28-58	5-12	4-10

Preparation of Asphalt Concrete Mixture and Specimens

The fine and coarse aggregates were combined with the mineral filler to meet the specified gradation for wearing course. The combined aggregates were then heated to 160ºC. The asphalt cement binder was heated to 150ºC, then, it was added to the heated aggregates mixture to achieve the desired amount and mixed thoroughly for two minutes until all aggregate particles were coated with a binder thin film. The optimum binder percentage was 4.9% and it was determined based on Marshall Trial mixes using various asphalt percentages. Details of obtaining the optimum binder content could be found in Sarsam and Al-Lamy, (2015). The mixtures were casted in a slab mold of (60 x 400 x 300) mm and subjected to roller compaction to the target bulk density according to EN12697-33, (2007). The applied static load was 5 kN. Details of the compaction process could be referred to Sarsam, (2016). The compaction temperature was maintained to 150°C. Slab samples were left to cool overnight. Beam specimens of 63±2 mm width and 50±2 mm height and 400 mm length were obtained from the compacted slab sample using the Diamond-saw. The total number of beam specimens obtained was twelve, while the number of casted slabs was three.

Four-Points Repeated Flexural Bending Beam Test

The four-points repeated flexural bending beam test was implemented according to AASHTO T321, (2010)to verify the influence of microstrain level on the permanent deformation of asphalt concrete beam specimens at various pavement operating temperature of (5, and 30) °C and under constant strain level of (750, 400 and 250) micro strain. Figure 1 exhibit the test setup.

Figure 1 Four-point flexural bending beam test setup

During the flexural fatigue test, the asphalt concrete beam is subjected to repeated four-point bending. The load frequency is set to 5 Hz and the vertical deformation caused by the loading is detected at the center of the beam. A repeated sinusoidal load (tension-compression) is applied on the two inner clamps on the asphalt concrete beam specimen while the outer clamps are providing a reaction load. The loading produces a uniform tension state and a constant bending moment along the central part of the beam. Thus, in this region, there are no shear stresses. The asphalt concrete beam specimens were subjected to a repeated load at a constant strain level of 400. The test was terminated when the stiffness of asphalt concrete beam specimens was declined to 50% of its original value. The test results presented are the average of three specimens.

3. RESULTS AND DISCUSSION

Influence of Testing Environment on Permanent Microstrain

As demonstrated in Figure 2, the permanent microstrain at 5℃ environment increases as the microstrain level increase. Such behavior is more pronounced after two seconds of repeated flexural stress loading. It can be noticed that after three seconds of loading, the permanent microstrain increases by (38.8 and 218) % when the microstrain level increases from 250 to 400 and 750 microstrain respectively. Similar behavior was reported by Sarsam, (2022).

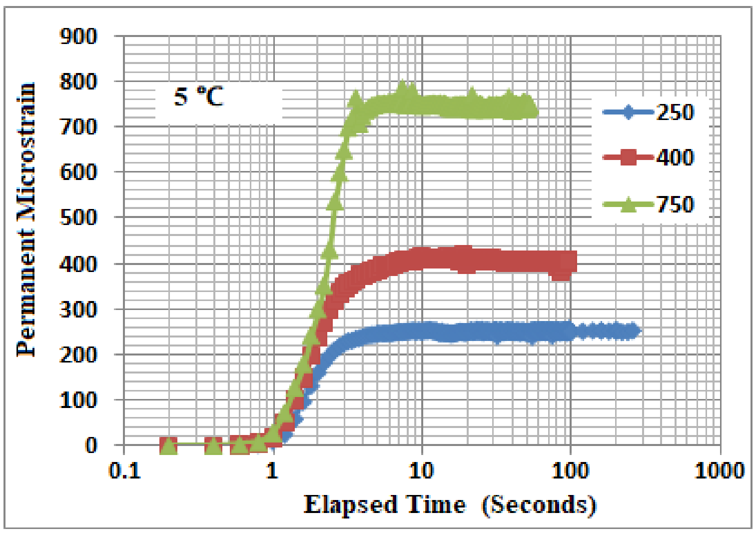

Figure 2 Impact of Microstrain Level on Deformation at 5℃ Environment

However, when the testing environment increases to 30℃as exhibited in Figure 3, the signs of failure are more pronounced as indicated by the sharp increase in the permanent microstrain at earlier stage of loading. As far as the thermal behavior of asphalt concrete is concerned, the permanent microstrain increases by (56.2, 33.3 and 153) % under microstrain levels of (250, 400 and 750) respectively at a testing environment of 30 °C as compared with that at testing environment of 5 °C. On the other hand, the initiation of failure in asphalt concrete starts earlier after 3 seconds of loading at 30℃ testing environments as compared with that after 2 seconds of loading at 5℃ environment. This behavior may be attributed to gain in the flexibility of asphalt concrete after the decline of binder's viscosity due to the rise in the testing temperature.

Influence of Testing Environment on Fatigue Life

The fatigue life increases as the testing temperature rises regardless of the microstrain level; this could be attributed to the reduction in the stiffness of asphalt concrete at higher testing temperature. The fatigue life of asphalt concrete mixture increases by (2.3, 14 and 12.3) folds under microstrain levels of (750, 400 and 250) respectively when the testing environment rises from (5 to 30)℃. This may be attributed to the decline in the stiffness of asphalt concrete at higher testing temperature of 30 ℃. On the other hand, the fatigue life decreases as the microstrain level increase regardless of the testing temperature. This may be related to the fast accumulation of damage in asphalt concrete since the asphalt concrete mixture exhibit lower resistance to the deformation at higher microstrain level. Such behavior agrees with Karimi et al., (2017).

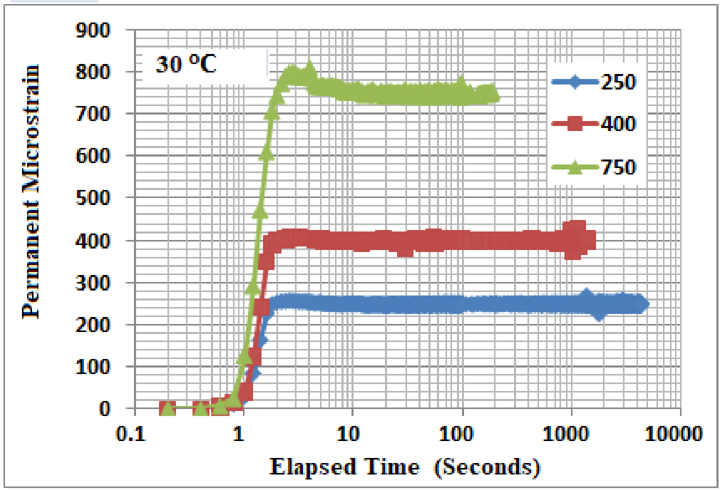

Figure 3 Impact of Microstrain Level on Deformation at 30℃ Environment

Modeling the thermal behavior of asphalt concrete

As demonstrated in Figure 4, Sharp trend of increase in the permanent deformation could be detected as the microstrain level increases, the permanent microstrain increases as the testing temperature and the strain level rises. Such thermal behavior was observed after three seconds of practicing the repeated flexural stresses. Wang et al., (2019) reported similar results.

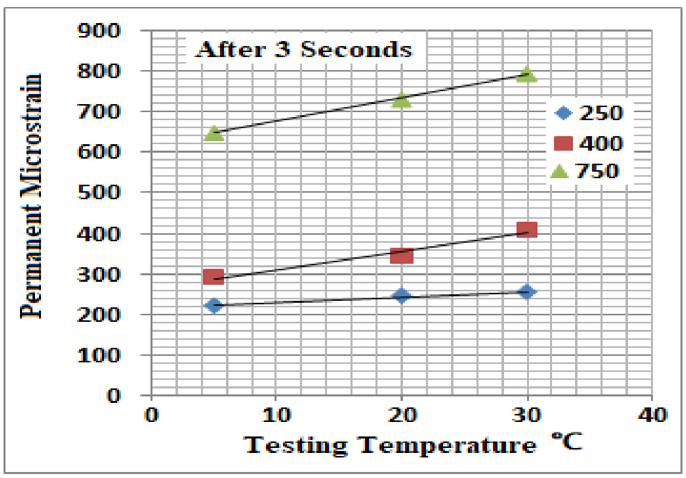

Figure 4 Thermal behavior under various Microstrain Levels

Table 5 exhibits the deformation parameters of asphalt concrete mixtures after three seconds of loading. A straight-line model with a high coefficient of determination could be found regardless of the microstrain level. The intercept which represents the permanent deformation at the initial stage of loading increases as the microstrain level rises. However, the slope which is an indication of the rate of increase in the permanent deformation also rises as the microstrain level increases. Sarsam, (2021) reported similar behavior.

Table 5 Permanent Deformation Parameters

Microstrain Level	Intercept	Slope	Mathematical Model	R^2
250	217.3	1.342	Y=217 + 1.342 x	0.980
400	265.9	4.510	Y=265.9 +4.510 x	0.971
750	619.4	5.810	Y=619.4 + 5.81 x	0.998

4. CONCLUSIONS

The following conclusions may be addressed based on the limitation of testing and materials. After three seconds of loading, the permanent microstrain increases by (38.8 and 218) % when the microstrain level increases from 250 to 400 and 750 microstrain

respectively. The permanent microstrain increases by (153, 33.3 and 56.2) % under microstrain levels of (750, 400 and 250) respectively at a testing environment of 30 °C as compared with that at testing environment of 5 °C. The initiation of failure in asphalt concrete starts earlier after 3 seconds of loading at 30 °C testing environment as compared with that after 2 seconds of loading at 5 °C environment. The fatigue life increases by (2.3, 14 and 12.3) folds under microstrain levels of (750, 400 and 250) respectively when the testing environment rises from (5 to 30)°C. The permanent microstrain increases as the testing temperature and the strain level rises. Such thermal behavior was observed after three seconds of practicing the repeated flexural stresses.

Ethical approval

Not applicable.

Informed consent

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

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Data and materials availability

All data associated with this study are present in the paper.

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